The University of Chicago

AN IMPROVED DESCRIPTION OF THE THORIUM SPECTRUM

A DISSERTATION SUBMITTED TO THE FACULTY OF THE DIVISION OF THE PHYSICAL SCIENCES IN CANDIDACY FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF PHYSICS

1937

By

MARK FRED

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ABSTRACT

Part of the spectrum of thorium has been separated into about 750 *Th* I lines and 2000 *Th* II lines (of which only the most important are given here), primarily on the basis of relative intensities in different parts of the arc gap. This classification has been confirmed by Zeeman patterns where resolved, by furnace data, etc. Certain of the lines of each spectrum have been designated as low-temperature lines. Most of the wave lengths are given to seven significant figures. It is believed that these data are sufficient for the term analysis of *Th* I. For *Th* II better Zeeman patterns are probably necessary.

I

The spectrum of thorium appears to have received very little attention since the work quoted in 1912 by Kayser,[1] who listed 1300 lines from 2400 A to 7000 A in Rowland units. No further wave lengths have been published except in the vacuum region, where *Th* IV has been analyzed by Lang.[2] The *raies ultimes* have been determined by De Gramont,[3] Pollok and Leonard,[4] and others. Allin[5] reports certain ultraviolet lines reversed in the underwater spark. The Zeeman patterns of a number of lines were partly resolved and measured by Moore.[6]

For a term analysis the foregoing data are quite inadequate. Since there are no obvious regularities, a start on a term scheme must be made by a search for constant differences and application of the combination principle. But it will be recalled that one can expect, by chance, approximately $2\epsilon N^2/I$ pairs with any given wave-number difference,[7] where ϵ is the wave-number error of the N lines considered in the total spectrum range I cm^{-1}. Moreover, some differences will be repeated by chance by more than this number of

[1] *Handbuch der Spectroscopie*, **6**, 636, 1912. [2] *Can. Jour. Res.*, **14**, 43, 1936.

[3] See F. Twyman, *Wavelength Tables for Spectral Analysis* (London: Adam Hilger), p. 114, 1931.

[4] Quoted by Twyman, p. 95.

[5] *Trans. Roy. Soc. Can.*, **21**, 231, 1927. [6] *Ap. J.*, **30**, 144, 1909.

[7] S. Goudsmit, quoted by G. R. Harrison, *Rev. Sci. Inst.*, **4**, 584, 1933.

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pairs, other differences by less; i.e., one expects a probability distribution (of the Poisson type) of the number of pairs, whose maximum is given by the foregoing expression. Since many thousand differences are examined to find those which are repeated, one desires the probability that any differences are repeated by chance several times to be less than one in some thousands. For this to be true the most probable number of pairs must be considerably less than one. From the expression $2\epsilon N^2/I$ one sees that this can be reduced by increasing the wave-length accuracy and by restricting N (preferably by subtracting only those lines expected to show the greatest number of constant differences, i.e., low-temperature lines). Of course, a term analysis is perfectly possible with a greater number of chance relationships, but experience suggests that considerable preliminary preparation is quite profitable.

Another obvious requirement is that the lines be classified as arc or spark. This difficulty is by no means trivial. Most of the lines show very little intensity change in the spark as compared with the arc as source, and some other criterion must be adopted. A convenient characteristic, which has been verified for similar elements, for example, hafnium,[8] is the enhancement of the spark lines at the cathode of the arc.

This paper presents material which to a certain extent satisfies the preceding objectives.

II

The wave lengths given below are taken from several sources. Most of them were measured by the writer on plates taken in this laboratory on the new thirty-foot grating, which has a dispersion of 0.9 and 0.4 A/mm in the first and second orders, respectively. The source was an arc between thorium electrodes in an atmosphere of nitrogen. The plates were measured on a Geneva comparator. Half of the iron comparison exposure was made before the thorium exposure, and the rest afterward. The 1928 wave lengths of the International Astronomical Union were used where available, supple-

[8] W. F. Meggers and B. F. Scribner, *Bur. Stand. Jour. Res.*, 13, 625, 1934.

mented by Burns's vacuum-arc interferometer measurements[9] in the ultraviolet. Second-order iron lines were used in the red, with 0.015 A added to the first-order wave lengths calculated from them to correct for failure of the grating law.

Through the courtesy of Professor G. R. Harrison, of the Massachusetts Institute of Technology, preliminary values were obtained for about twelve hundred selected thorium lines from 4436 A to 2826 A, measured by means of an automatic measuring machine on plates taken with a thirty-five-foot grating. Harrison states that similar measurements on the cobalt spectrum show an average deviation of 0.002 A from interferometer measurements, and the final thorium values are expected to be as good, each wave length being the average of three to ten determinations. The second-order ultraviolet wave lengths described above agree with Harrison's values to within an unweighted average of 0.004 A, while the first-order visible lines spread, by about the same amount, about a systematic difference of 0.005 A. From this agreement the average wave-number error for lines measured by the writer may be expected to be about 0.02 or 0.03 cm^{-1}.

The remaining wave lengths, given to six figures, are taken from earlier work done by the writer[10] with M. Ference, Jr.,[11] and with R. B. Bowersox.[12] These measurements (on 6000 lines) were made on plates taken in the first order of a twenty-one-foot grating which had a dispersion of 2.4 A/mm. The source was a hollow cathode discharge in which $ThCl_4$ was vaporized and excited by helium. The values are good to about 0.01 or 0.02 A, except in the infrared, where the wave-length error is somewhat more.

The separation of the lines quoted below into two tables was made purely on the basis of relative intensities at different parts of the arc gap: lines which were definitely enhanced at the anode were called *Th* I; lines having equal intensity all the way across the arc and lines enhanced at the cathode were called *Th* II or *Th* III. This classification is in agreement with practically all the available Zeeman patterns and furnace data. The intensities quoted are visual estimates,

[9] K. Burns and F. M. Walters, Jr., *Pub. Allegheny Obs.*, **8**, No. 4, 39, 1931.

[10, 11, 12] Master's dissertations, University of Chicago, 1934.

TABLE 1

THORIUM I

λ	ν	− o +	Remarks
8967.65	11148.19	 2	
8758.22	414.71	 2	
8748.02	28.02	 3	
8573.10	661.19	.. o 3	
8478.36	791.50	.. o 5	
8446.51	835.96	.. o 4	
8445.46	37.43	 2	
8421.22	71.52	.. o 4	
8417.98	76.07	 3	
8416.70	77.88	.. o 6	
8330.48	12000.82	.. o 9	
8320.86	14.69	.. o 5	
8275.63	80.35	.. o 3	
8186.92	211.26	.. o 3	
8159.75	51.91	.. o 2	
8143.15	76.89	.. o 3	
8032.48	446.04	 2	
7978.97	529.50	 6	
7900.35	54.19	 2	
7865.99	709.47	 2	
7847.53	39.36	 6	
7817.78	87.85	 5	
7798.33	819.74	 2	
7788.95	35.17	oo .. 4	
7653.86	13061.71	 2	
7647.40	72.75	1 o 8	
7585.73	179.03	2 o 9	
7567.72	210.39	2 o 6	
7549.33	42.57	oo .. 3	
7483.62	358.84	.. oo 3	
7481.36	62.88	.. o 4	
7447.84	423.02	 2	
7444.75	28.58	 2	
7430.27	54.76	o o 6	
7428.96	57.13	2 1 8	
7418.57	75.98	 2	
7402.31	505.58	o oo 2	
7385.485	36.30	3 2 8	
7384.21	38.69	 3	
7383.74	39.54	o .. 3	
7376.95	52.00	o .. 4	
7341.20	618.01	o o 4	
7328.34	41.90	o o 5	
7324.86	48.39	o .. 2	
7288.98	715.57	.. o 3	

TABLE 1—*Continued*

λ	ν	− o +	Remarks
7287.05	13719.20	.. o 2	
7284.95	23.15	.. o 5	
7244.73?	99.33	 2	
7242.09	804.37	 2	
7230.88	25.78	 2	
7219.18	48.18	 2	
7218.11	50.23	3 1 6	?
7217.79	50.84	 4	?
7212.75	60.53	o .. 4	
7208.005	69.56	2 1 8	
7206.55	72.45	 2	
7200.08	84.91	 3	
7173.42	936.51	oo .. 3	
7168.888	45.34	2 2 10	
7164.88	53.13	 2	
7159.08	62.68	 3	
7159.10	64.39	o o 4	
7158.56	65.45	 2	
7156.98	68.53	o .. 2	
7155.55	71.32	o o 3	
7155.05	72.30	o o 3	
7153.61	76.11	oo .. 2	
7150.34	81.50	oo .. 3	
7148.59	84.94	oo oo 3	
7124.61	14032.00	1 o 5	
7084.177	112.08	 6	
7064.48	51.43	 2	
7060.71	58.99	 2	
7036.30	208.10	 2	
7018.574	43.99	 5	
7000.795	80.16	 6	
6989.657	302.92	1 .. 8	
6943.610	97.77	o .. 7	
6911.238	465.20	o .. 7	
6874.77	541.94	o .. 2	
6868.55	55.11	o .. 2	
6834.921	626.72	o .. 6	
6829.05	39.30	 5	
6824.73	48.56	 4	
6809.35	81.64	 2	
6791.27	720.73	 3	
6789.028?	25.59	o .. 2	
6787.917?	28.00	o .. 2	
6780.268	44.62	2 .. 7	
6780.147	44.88		

TABLE 1—*Continued*

λ	ν	− o +	Remarks
6778.451?.....	14748.57	 3	
6772.283.....	62.00	 2	
6713.971.....	890.21	 2	
6678.711.....	968.82	o .. 2	
6674.701.....	77.82	o ... 2	
6662.274.....	15005.75	3 4 8	fl
6658.681.....	13.85	o 1 2	fl
6593.96.....	161.21	2 3 6	
6591.480.....	66.92	2 2 5	
6588.540.....	73.69	2 3 6	
6583.907.....	84.36	3 3 5	
6577.203.....	99.84	2 2 4	
6554.148.....	253.31	o 1 2	
6531.348.....	306.55	3 4 7	fl
6512.365.....	51.17	o 1 2	
6501.991.....	75.67	1 1 2	
6493.198.....	96.48	.. 1 2	
6457.286.....	482.11	4 5 9	fl
6413.596.....	587.59	2 3 3	w fl?
6411.884.....	91.74	3 4 5	fl?
6390.129.....	644.82	o o 1	w fl
6376.950.....	77.15	3 4 5	fl
6371.951.....	89.45	1 2 3	
6369.141.....	96.37	2 2 3	
6355.632.....	729.74	.. o 2	
6342.864.....	61.40	5 6 8	fl
6337.615.....	74.45	o o 2	
6331.408.....	89.92	o o 2	
6327.163?.....	800.51	2 3 5	fl
6326.356.....	02.53	o 1 2	
6266.167.....	954.31	6 7 8	fl
6234.851.....	16034.45	o 2 4	fl
6224.508.....	61.09	1 2 4	w fl
6207.744.....	104.47	2 3 5	w fl
6207.217.....	05.79	1 1 2	
6203.488.....	15.69	2 2 3	w fl
6198.219.....	29.21	1 2 3	w fl
6191.912.....	45.64	1 2 3	w fl
6184.729.....	64.39	4 4 5	
6182.629.....	69.88	3 4 6	fl
6170.71.....	201.12	.. o 1	w fl
6169.822.....	03.45	2 3 6	fl
6164.476.....	17.50	o 1 2	
6151.991.....	50.41	2 3 4	fl
6121.414.....	331.58	1 2 3	s fl

TABLE 1—*Continued*

λ	ν	−	o	+	Remarks
6102.596	16081.95	0	1	3	w fl
6088.037	421.12	0	1	2	
6053.380	515.14	0	1	2	
6049.058	26.93	..	0	3	w fl
6037.705	58.01	1	2	3	w fl
6021.038	603.84	2	2	3	w fl
6010.162	33.89	0	1	2	
6007.075	42.44	1	2	3	
6000.769	59.93	2	3	4	
5994.136	78.36	2	3	4	fl
5991.014	87.05	0	1	2	
5975.070	731.58	3	4	5	w fl
5973.671	35.50	2	3	5	fl
5938.835	833.67	4	5	6	fl
5885.704	985.62	..	..	2	
5804.12	17224.4	3	4	6	
5800.80	34.2	0	1	3	
5792.435	59.12	00	0	2	
5767.781	332.89	00	0	2	
5760.553	54.64	6	7	9	fl
5753.028	77.34	1	2	3	
5725.389	461.23	2	3	4	
5720.183	77.12	4	4	5	fl
5719.621	78.84	2	2	3	
5677.054	609.90	0	1	2	
5665.180	46.80	1	1	2	
5657.926	69.43	1	1	2	
5601.613	847.06	0	1	2	
5599.782	52.90	0	1	2	
5599.665	53.27				
5595.076	67.91	1	2	3	
5587.032	93.64	2	3	4	fl
5579.377	918.19	2	3	3	
5576.216	28.34	2	2	3	
5573.364	37.52	2	3	4	
5572.478	40.37	2	2	3	
5571.202	44.48	2	2	4	
5559.903	80.94	1	2	3	
5558.346	85.98	3	3	4	
5548.085	18019.25	3	3	5	
5542.907	36.08	2	2	3	
5539.270	47.92	3	3	4	
5519.001	114.20	1	1	2	
5514.876	27.75	1	1	2	
5509.999	43.79	2	2	3	

TABLE 1—*Continued*

λ	ν	− o +	Remarks
5504.313	18162.54	1 1 3	
5499.257	79.24	2 2 4	
5492.645	201.12	0 1 2	
5431.129	407.28	1 1 2	
5417.485	53.63	2 3 4	
5410.73	76.7	1 1 2	
5407 61	87.4	1 1 2	
5398 88	517 2	1 2 3	
5394.71	31.6	0 1 2	
5386.56	59.6	1 1 2	
5378.79	86.4	0 1 2	
5343.55	709.0	2 3 4	
5326.95	67.3	1 2 3	
5312.88	817.0	1 2 3	
5312 50	18 3		
5311.97	20.2	1 2 3	
5297 74	70 7	1 1 3	
5289.88	98.8	1 0 2	
5266.67	982.1	0 0 2	
5260.08	19005.8	00 00 2	
5258.34	12.1	2 3 5	
5238 80	83 0	00 0 2	
5231 14	111 0	2 3 5	
5219.10	55.1	1 2 3	
5213.35	76.2	0 0 2	
5211.23	84.0	1 2 4	
5203 85	211 1	1 1 2	
5199.113	28.71	1 2 3	
5195.769	41.09	2 2 3	
5176.94	311.1	2 1 3	1?
5161.537	68.69	0 1 2	
5158.615	79.66	2 2 3	
5154.246	96.09	1 2 2	
5143.919	435.03	1 1 2	
5132.239	79.26	1 1 2	
5100.615	600.03	1 1 2	
5096.476	15.95	0 1 2	
5067.983	726.23	2 2 3	w fl
5039.236	838.76	1 1 2	
5002 105	986 03	1 2 3	
4989.320	20037.24	0 0 2	
4985.385	53.05	1 1 2	
4945.465	214.92	1 1 2	
4937.827	46.19	1 1 2	
4894.948	423.54	2 2 3	w fl; fur

TABLE 1—*Continued*

λ	ν	− o +	Remarks
4878.739	20491.39	1 1 2	fur
4874.366	509.78	1 1 2	
4861.220	65.24	1 1 2	
4848.355	619.81	1 2 3	w fl; fur
4840.831	51.86	1 2 2	fur
4826.699	712.32	1 1 2	
4826.40	13.6	.. oo oo	fur
4813.907	67.36	1 1 2	
4813.714	68.19		
4809.625	85.85	1 1 2	fur
4808.127	92.33	2 2 3	w fl; fur
4795.93	845.2	0 0 2	
4789.381	73.71	2 2 3	fur
4786.535	86.12	1 1 2	
4778.287	922.17	1 2 3	fur
4777.188	27.00	1 2 3	
4766.595	73.49	1 1 2	fur
4758.147	21010.73	1 1 2	fur
4729.114	139.72	1 0 2	
4703.992	252.61	1 1 3	fl
4691.638	308.57	oo oo 2	u w sp?
4676.057	79.57	1 1 2	v w fl; u w sp
4669.986	407.37	1 1 2	v w fl
4668.177	15.66	1 1 2	w fl
4666.798	22.00	1 1 2	
4592.668	767.76	2 2 3	w fl
4570.990	870.99	2 2 3	w fl
4561.364	917.14	2 2 3	
4555.917	43.35	2 2 3	fl; u w sp
4555.825	43.79		
4552.172	61.40	1 1 2	w fl
4545.264	22043.27	1 1 2	
4530.338	67.24	1 1 2	
4515.135	141.54	1 1 2	fur
4482.170	304.38	1 1 2	fur
4458.009	425.27	2 2 3	w fl; fur; u w sp
4452.576	52.63	1 1 2	
4408.886	675.12	4 4 5	w fl; fur
4378.183	834.13	1 1 2	w fl; fur
4311.808	23185.63	1 0 2	
4307.183	210.52	1 1 2	
4299.849	50.11	1 1 2	v w fl
4288.677	310.68	1 1 2	
4253.552	503.17	1 1 2	
4235.470	603.51	1 1 2	fur

TABLE 1—*Continued*

λ	ν	−	o	+	Remarks
4227.661	23647.11	1	1	2	
4213.073	728.98	1	1	2	
4210.928	41.07	2	3	4	fl; fur
4210.768	41.97				
4193.00	842.6	1	1	2	w fl
3980.090	25117.02	1	1	2	
3973.228	61.36	1	2	2	
3972.160	68.13	1	2	2	
3941.731	302.41	1	2	2	v w fl
3941.364	64.77				
3935.642	401.65	2	2	3	
3932.951	19.03	2	2	3	
3919.003	509.50	1	2	3	
3911.914	55.72	1	1	2	
3875.647	794.86	2	2	3	
3873.825	806.99	3	3	4	w fl
3869.981	32.62	1	1	2	
3869.670	34.70				
3869.504	53.25	1	1	2	
3852.142	952.25	2	2	3	
3851.160	58.87	0	0	2	
3846.888	87.70	1	1	2	
3845.095	99.82	0	0	2	
3845.016	26000.35				
3842.912	14.58	2	2	3	
3835.413	65.44	0	0	2	
3835.345	65.91				
3830.061	101.86	0	0	2	
3828.389	13.76	3	4	5	fl
3822.862	51.02	1	1	2	
3818.671	79.72	0	1	2	
3817.375	88.61	1	1	2	
3817.290	89.19				
3811.065	231.97	1	2	3	
3808.612	48.86	0	1	2	
3803.983	80.80	2	2	3	
3803.079	87.05	3	4	4	fl; fur
3801.446	98.34	2	2	3	
3780.972	440.74	1	2	2	
3771.379	508.00	2	3	3	w fl; fur
3759.314	93.07	1	2	2	w fl
3757.699	604.50	1	2	2	w fl
3755.217	22.08	1	2	2	
3754.035	30.46	1	2	2	
3742.922	709.53	2	3	3	

TABLE 1—*Continued*

λ	ν	−	o	+	Remarks
3727.901	26817.15	1	2	2	w fl
3698.113	27033.15	1	2	2	w fl
3661.622	302.55	2	2	3	w fl
3658.808	23.55	0	1	2	w fl; fur
3649.733	91.49	1	2	2	w fl
3642.255	447.72	3	4	4	fl; fur
3635.942	95.38	1	2	2	w fl
3634.580	505.68	1	2	2	w fl
3612.868	671.21	1	2	2	w fl; fur
3612.429	74.34	2	2	3	w fl; fur
3598.123	784.37	2	3	3	fl; fur
3592.777	825.71	2	2	3	w fl
3591.454	35.96	1	2	2	w fl
3576.558	951.89	2	3	3	w fl
3526.629	28347.62	0	1	1	fur
3521.062	92.84	0	1	2	fur
3518.402	413.90	1	1	2	w fl; fur
3511.154	72.55	0	0	1	fur
3498.625	574.51	0	1	1	fur
3496.809	89.35	1	1	2	fur
3495.705	98.38	0	1	2	fur
3489.511	649.14	00	0	0	fur
3488.837	54.67	00	0	0	fur
3486.520	73.72	3	3	4	fl; fur
3469.337	815.73	1	2	2	w fl; fur
3466.646	38.10	1	2	3	fl; fur
3466.532	39.05				
3461.216	83.34	..	..	..	fur; 1?
3461.022	84.96	4	5	4	fur
3457.069	917.98	0	0	1	fur
3451.699	62.97	1	2	2	fur
3442.580	29039.69	0	0	1	fur
3437.303	84.27	2	3	3	w fl; fur
3436.680	89.54	1	2	2	w fl; fur
3428.990	154.78	1	1	2	fur
3423.991	97.34	2	3	3	w fl; fur
3421.174	221.38	2	3	3	w fl; fur
3417.494	52.85	0	0	1	fur
3398.548	415.92	0	1	1	fur
3397.518	24.84	0	1	1	fur
3380.883	569.60	0	1	1	fur
3374.979	621.33	0	1	1	w fl; fur
3373.500	34.32	0	0	1	fur
3372.794	40.52	0	0	1	fur
3372.696	41.39				

TABLE 1—*Continued*

λ	ν	−	o	+	Remarks
3365.336.....	29706.21	o	o	1	fur
3333.129.....	993.24	1	2	2	fur
3313.651.....	30169.54	oo	o	1	fur; u w sp
3309.361.....	208.65	o	1	1	fur
3301.654.....	79.17	o	1	1	v w fl; fur; u w sp
3285.750.....	425.72	o	o	1	fur
3272.025.....	553.34	o	1	1	fur
3253.872.....	723.79	o	1	2	fur
3244.450.....	813.00	o	1	1	fur
3232.307.....	928.76	o	1	2	fur
3232.123.....	30.52	o	1	2	fur
3116.281.....	32080.23	2	2	3	w fl; u w sp

on a scale 00:10, of lines photographed with a stigmatic spectrograph (Wadsworth mounting) which had a dispersion of 5 A/mm. Both arc and spark sources were used, and the plates were examined by projection with such magnification that wave lengths could be identified directly to 0.2 A, with a centimeter scale. Some close lines are bracketed together with the same intensity: this is due to the poor resolving-power of this type of grating mounting and means that the indicated intensity is the sum of both lines and that either or both are enhanced accordingly. The minus (−), zero (o), and plus (+) headings mean intensities at the cathode, the center, and the anode of the arc.

Observation of the stigmatic images showed that some lines persisted with appreciable intensity for a much greater length than the geometrical image of the arc gap. These flame lines have been called "low-temperature lines" and are designated by "fl" in the tables ("w fl" for weak flame). Flame lines were found for both *Th* I and *Th* II.

It has been possible to confirm the temperature classification assumed above through the kindness of Dr. A. S. King, of the Mount Wilson Observatory, who at the writer's request very graciously consented to photograph the furnace emission spectrum. The region from 5050 A to the ultraviolet limit of the furnace emission was covered and the lines were identified partly by Dr. King and

TABLE 2

THORIUM II

λ	ν	−	o	+	Remarks
7525.52	13284.46	10	6	8	R; w fl
7393.433	521.75	10	5	7	R; w fl
6619.877	15101.86	10	10	10	w fl
6605.432	34.88	9	9	9	fl
6279.175	921.26	7	7	6	w fl
6274.105	34.13	10	10	10	fl
6261.064	67.32	10	10	10	w fl
6248.091	16000.57	3	2	2	w fl
6112.840	354.49	10	10	10	fl
6104.581	76.62	6	6	5	w fl
6073.106	461.49	10	10	10	w fl
6044.439	539.56	9	9	8	w fl
5998.048	692.53	15	15	15	s fl
5925.895	870.42	5	5	5	w fl
5925.413	71.80	3	3	2	w fl
5914.400	903.21	15	15	12	s fl
5707.097	17517.19	9	8	7	fl; u w sp
5700.915	36.19	10	9	9	fl
5639.746	726.39	9	6	5	fl
5615.324	803.48	2	2	2	u w sp
5568.019	954.74	5	3	3	u w sp
5415.425	18460.65	6	4	4	u w sp
5143.272	19437.48	4	2	2	u w sp
5110.853	560.77	2	1	1	u w sp
5049.805	797.24	6	4	4	fl; fur; u w sp; $J' \neq J''$
5044.72	817.2	2	2	2	fur
5028.610	80.68	4	3	2	u w sp
5017.249	925.70	7	4	4	w fl; u w sp
4987.167	20045.89	5	3	2	u w sp
4954.665	177.38	4	2	2	R?; fur; u w sp
4954.569	77.77				
4919.812	320.32	8	5	5	fl; u w sp
4872.92	515.9	2	1	2	fur; u w sp; II?
4863.167	57.01	8	6	4	fl; u w sp
4858.336	77.45	3	2	1	u w sp
4850.434	610.97	4	2	2	w fl; u w sp
4849.042	16.89	2	1	1	u w sp
4840.468	53.41	2	2	1	u w sp
4832.798	86.51	4	2	2	w fl
4831.15	93.3	2	2	2	v w fl; fur
4818.657	746.89	3	2	1	u w sp
4800.175	826.77	3	1	0	u w sp
4761.108	997.66	4	2	2	u w sp
4752.401	21036.13	6	4	4	fl; u w sp; 7/2−7/2
4740.515	88.87	3	2	2	fl; u w sp; 7/2−7/2
4729.89	136.3	2	1	0	u w sp

TABLE 2—*Continued*

λ	ν	−	o	+	Remarks
4723.773	21163.61	4	2	2	fl; u w sp
4723.436	65.13	3	2	3	fl; u w sp; II?
4718.615	86.75	2	2	2	u w sp
4706.348?	241.97	1	1	1	u w sp
4694.091	97.44	2	1	1	fl
4689.169	319.79	2	1	2	w fl; u w sp; II?
4673.65	90.6	2	1	2	fl; II?
4651.562	492.16	2	1	1	fl; u w sp
4641.259	539.87	1	0	0	u w sp
4639.708	47.07	2	1	0	u w sp
4633.833	74.38	2	1	1	w fl
4633.753	74.76				
4631.761	84.03	3	2	2	fl; u w sp; $J' \neq J''$
4623.893	620.76	2	1	0	u w sp
4619.557	41.06	3	1	1	fl; u w sp
4619.472	41.45				
4609.363	88.92	2	1	0	u w sp
4603.15	718.2	2	2	2	w fl
4602.90	19.4				
4595.42	54.7	3	3	3	fl
4588.42	87.9	3	3	3	fl
4563.66	906.1	3	2	3	fl; fur; II?
4563.316	07.77	3	2	2	fl; fur; u w sp; 63.2: 1/2−3/2
4563.228	08.19				
4537.11	22034.3	3	2	2	fur
4534.130	48.79	3	1	1	fl
4510.548	164.06	6	5	5	fl; u w sp
4505.226	90.24	1	1	1	w fl
4499.96	216.2	2	1	2	fur; II?
4498.93	21.3	3	2	3	fl; II?
4493.31	49.1	5	5	5	fl; fur
4487.500	77.89	4	2	1	fl; fur
4480.822	311.09	3	3	3	w fl
4465.577	87.26	4	3	2	fl (prob. 65.3); 65.3: 5/2−7/2
4465.351	88.40				
4447.844	476.51	4	2	2	fl; 1/2−3/2
4440.876	511.78	4	2	2	fl; 3/2−5/2
4439.137	20.60	4	2	2	fl; $J' = J''$
4432.963	51.96	5	4	4	fl; u w sp
4412.744	655.29	6	5	4	fl; u w sp
4412.530	56.40				
4402.93	705.8	2	2	2	w fl
4391.106	66.93	8	6	6	R; fl; u w sp; P_1; 5/2−7/2?
4381.860	814.97	7	5	4	fl; u w sp; P_1; 1/2−1/2??
4374.788	51.85	3	2	2	w fl
4374.139	55.24	3	2	2	w fl; fur

TABLE 2—*Continued*

λ	ν	−	o	+	Remarks
4350.849	22977.58	2	2	1	fl
4344.99	23008.6	2	2	1	fl
4338.07	45.3	1	1	1	v w fl
4337.398	48.85	2	2	1	w fl
4337.282	49.46				
4313.003	179.21	3	2	2	fl; fur
4310.002	95.39	3	2	2	w fl; u w sp
4295.08	275.9	2	1	0	u w sp
4282.050	346.76	7	5	4	fl; u w sp; 7/2−9/2
4277.327	72.53	6	4	4	fl; u w sp; 3/2−3/2
4273.363	94.22	3	2	1	fl; u w sp
4260.33	465.7	2	1	2	w fl; II?
4257.501	81.37	2	2	2	w fl; fur
4256.229	88.39	3	2	2	w fl; low *J*
4250.337	520.95	3	2	2	fl; fur
4208.897	752.49	7	5	5	fl; u w sp; 1/2−1/2 or 3/2
4201.853	92.34	3	1	1	v w fl; u w sp
4195.957	825.77	1	0	0	u w sp
4195.836	26.46	0	0	0	
4179.969	916.90	4	3	2	fl; u w sp
4179.725	18.30				
4178.068	27.79	3	2	2	fl; u w sp; 5/2−5/2
4171.353	66.31	1	..	..	u w sp
4170.543	70.95	2	2	2	w fl; u w sp
4170.472	71.37				
4168.96	80.1	1	1	1	u w sp
4168.62	82.0	1	1	1	
4163.652	24010.63	1	0	0	u w sp
4162.691	16.18	1	1	1	u w sp
4159.669	33.62	1	0	0	u w sp
4156.520	51.83	3	2	2	fl; u w sp
4149.992	89.66	2	2	2	w fl; u w sp
4148.179	100.19	2	1	1	u w sp
4142.702	32.08	3	2	2	fl; u w sp
4142.474	33.38				
4132.752	90.15	1	0	0	u w sp
4116.719	284.36	2	2	2	fl; P_2; u w sp; 7/2−9/2
4115.767	89.98	2	2	2	fl
4112.762	307.72	2	2	2	w fl; fur
4110.876	18.88	2	2	2	u w sp
4110.638	20.29				
4108.429	33.36	4	3	2	fl; u w sp; 1/2−3/2 or 1/2
4105.028	48.18	1	1	1	u w sp
4100.838	78.40	2	1	0	u w sp
4097.751	96.77	1	1	1	R? fur
4097.686	97.16				

TABLE 2—*Continued*

λ	ν	−	○	+	Remarks
4094.740	24414.68	4	3	2	fl; u w sp; 3/2−3/2
4086.524	63.79	3	3	3	fl; u w sp; 3/2−5/2
4085.042	72.67	3	3	3	u w sp
4069.204	567.92	4	3	3	fl; u w sp; 3/2−5/2
4041.205	738.13	2	1	1	u w sp
4036.564	66.57	2	1	1	w fl
4036.056	69.69	2	1	2	w fl; fur; II?
4030.854	801.66	2	2	2	w fl; fur
4019.143	73.92	8	6	5	R; fl; P_2; fur; u w sp; 3/2−5/2
4012.501	915.10	2	2	2	w fl; fur
4003.310	72.20	4	2	2	u w sp
4003.103	73.60				
3996.063	25017.59	2	1	1	u w sp
3994.554	27.03	4	3	3	fl; u w sp
3988.016	68.06	2	1	1	u w sp
3981.111	111.54	2	1	1	u w sp
3976.418	41.18	3	2	2	v w fl
3967.412	98.24	3	2	2	fl; fur; u w sp
3956.682	266.58	4	2	1	u w sp
3951.521	99.58	3	2	1	u w sp
3950.392	306.81	2	1	2	fur; u w sp; II?
3948.970	15.92	2	2	2	u w sp
3945.515	38.09	3	2	1	u w sp
3944.260	46.15	2	1	1	u w sp
3929.670	440.25	5	4	3	fl; u w sp; 3/2−5/2
3927.178	56.39	2	1	1	u w sp
3925.095	69.90	2	2	2	w fl
3916.732	524.29	3	1	1	u w sp
3905.188	99.73	3	2	2	u w sp
3900.885	627.97	5	3	3	v w fl; u w sp
3895.424	63.90	4	3	3	v w fl; fur
3886.918	720.06	2	2	2	fur
3885.154?	31.74	3	2	2	u w sp
3884.829	33.89	1	..	..	
3872.729	814.30	4	3	3	u w sp
3863.414	76.53	3	3	3	w fl; u w sp
3859.84	900.5	5	4	4	fl; fur
3854.514	36.28	3	3	3	u w sp
3841.965	26020.90	4	3	3	w fl; u w sp
3839.686	36.45	5	4	4	fl; u w sp
3831.736	90.46	3	2	2	u w sp
3825.043	136.01	2	2	2	u w sp
3822.144	55.93	2	2	2	u w sp
3821.430	60.82	2	2	2	u w sp
3813.063	218.22	4	3	2	u w sp

TABLE 2—*Continued*

λ	ν	−	o	+	Remarks
3807.872	26253.97	4	3	2	u w sp
3805.824	68.09	2	2	2	u w sp
3789.115	383.92	3	3	2	fl
3785.605	408.38	3	3	2	w fl; u w sp
3783.295	24.51	5	3	2	w fl; u w sp
3765.25	551.1	2	2	2	v w fl
3762.883	67.85	3	2	2	fl; u w sp
3752.573	640.84	5	3	0	w fl; u w sp
3741.187	721.92	8	5	4	R; fl; P_2; u w sp
3721.833	860.87	5	4	4	fl; u w sp
3720.00	74.0	3	3	3	fl; u w sp
3719.83	75.3				
3719.434	78.20	3	3	3	fl; fur
3711.312	937.01	..	..	..	P_2; u w sp
3706.769	70.03	3	3	3	w fl; u w sp
3675.572	27198.94	3	3	3	w fl; u w sp
3669.94	240.7	3	3	3	v w fl
3659.632	317.40	3	3	3	w fl; fur; u w sp
3658.068	29.08	..	..	..	fur; u w sp; II?
3625.924	571.35	3	2	2	v w fl; u w sp
3625.625	73.62	4	3	2	w fl; u w sp
3617.126	638.40	4	3	2	u w sp
3617.023	39.19				
3615.131	53.65	4	3	3	w fl
3609.445	97.21	4	3	2	fl; u w sp
3603.207	745.17	4	3	2	v w fl; u w sp
3601.040	61.86	3	2	1	u w sp
3575.317	961.60	4	3	3	v w fl; u w sp
3567.265	28024.71	3	2	2	v w fl; fur
3559.960	82.22	..	..	..	u w sp; II?
3559.457	86.18	..	..	..	u w sp; II?
3553.110	136.35	..	..	..	u w sp; II?
3545.288	98.43	..	..	..	u w sp; II?
3539.588	243.84	5	4	4	fl; fur; u w sp
3539.324	45.94	3	2	1	fur
3538.846	49.75	..	..	..	P_2; II?
3528.948	328.99	4	3	2	u w sp
3528.823	29.99				
3521.919	85.53	..	..	..	u w sp; II?
3516.824	426.65	..	..	..	u w sp; II?
3507.522	502.03	..	..	..	u w sp; II?
3493.517	616.39	..	..	..	u w sp; II?
3471.219	800.10	1	1	1	fur
3469.928	10.82	4	3	3	v w fl; P_2; fur; u w sp
3468.221	25.00	3	2	2	v w fl; u w sp

TABLE 2—*Continued*

λ	ν	− o +	Remarks
3465.929	28844.06	4 3 2	v w fl; u w sp
3465.763	45.45		
3463.723	62.43	.. .. ..	u w sp; II?
3462.854	69.68	.. .. ..	u w sp; II?
3452.679	954.75	3 2 1	
3439.713	29063.89	.. .. ..	u w sp; II?
3438.952	70.32	.. .. ..	u w sp; II?
3435.970	95.56	3 3 2	w fl; fur; u w sp
3433.998	112.26	3 3 2	w fl; u w sp; 3/2—5/2
3422.657	208.72	1 1 0	fur
3413.015	91.23	1 1 1	v w fl; fur
3408.748	327.90	1 1 0	fur
3405.560	55.35	1 1 1	fur
3402.701	80.02	.. .. ..	P_2; u w sp; II?
3396.733	431.64	1 1 1	fur?
3392.041	72.35	5 4 4	fl; R; fur; u w sp
3389.464	94.75	.. .. ..	fur; II?
3380.49	573.1	1 0 0	v w fl
3378.579	89.78	.. .. ..	u w sp; II?
3376.847	604.95	.. .. ..	u w sp; II?
3371.799	49.27	.. .. ..	u w sp; II?
3367.823	84.28	.. .. ..	u w sp; II?
3366.526	95.71	.. .. ..	u w sp; II?
3358.606	765.73	2 1 0	fur; u w sp
3354.614	801.15	.. .. ..	P_4; II?
3354.185	04.97	.. .. ..	P_4; u w sp; II?
3351.230	31.25	3 2 2	v w fl; P_4; fur
3348.777	53.23	2 2 2	v w fl; fur
3343.613	99.19	.. .. ..	u w sp; II?
3337.869	950.65	.. .. ..	u w sp; 3/2—5/2
3334.605	79.97	3 2 1	v w fl; P_4; u w sp
3330.475	30017.14	2 2 2	v w fl; fur
3327.196	46.72	1 0 0	fur
3325.125	65.44	4 3 2	v w fl; P_4; u w sp
3321.445	98.72	.. .. ..	u w sp; II?
3310.248	200.55	.. .. ..	u w sp; II?
3304.238	55.48	2 2 2	v w fl; fur
3301.351	81.94	.. .. ..	u w sp; II?
3300.611	88.73	.. .. ..	P_2; II?
3298.054	312.21	1 0 0	fur
3292.521	63.15	2 2 2	v w fl; u w sp
3291.744	70.31	3 2 2	v w fl; u w sp
3290.59	80.9	.. .. ..	P_1; u w sp; II?
3275.070	524.93	.. .. ..	u w sp; II?
3262.672	640.93	.. .. ..	u w sp; 7/2—7/2

TABLE 2—*Continued*

λ	ν	− o +	Remarks
3257.35.....	30690.9	2 2 2	fur
3256.115.....	702.62	.. .. ..	u w sp; II?
3251.917.....	42.26	1 1 1	fur
3245.764.....	800.53	.. .. ..	u w sp; II?
3238.118.....	73.26	.. .. ..	u w sp; II?
3235.842.....	94.97	.. .. ..	u w sp; II?
3229.011?.....	960.33	.. .. ..	u w sp; II?
3225.409.....	94.90	.. .. ..	u w sp; II?
3221.288.....	31034.55	.. .. ..	u w sp; II?
3216.632.....	79.47	.. .. ..	u w sp; II?
3198.232.....	258.27	.. .. ..	u w sp; II?
3188.234.....	356.29	4 3 2	v w fl; P_2; u w sp
3180.194.....	435.55	4 3 3	R; v w fl; u w sp
3175.730.....	79.74	.. .. ..	u w sp; II?
3154.771.....	688.87	.. .. ..	u w sp; II?
3151.651.....	720.24	.. .. ..	u w sp; II?
3150.456.....	32.27	.. .. ..	u w sp; II?
3148.06.....	56.3	.. .. ..	u w sp; 1−2? II?
3146.036.....	76.85	.. .. ..	u w sp; II?
3142.837.....	809.19	.. .. ..	u w sp; II?
3141.848.....	19.20	.. .. ..	P_4; II?
3139.306.....	44.98	.. .. ..	P_4; II?
3125.463?.....	986.00	.. .. ..	u w sp; II?
3124.388.....	97.02	.. .. ..	u w sp; II?
3122.957.....	32011.67	.. .. ..	u w sp; II?
3119.530.....	46.85	3 3 2	v w fl; u w sp
3108.295.....	162.68	.. .. ..	P_2; u w sp; II?
3088.473.....	369.05	.. .. ..	u w sp; II?
3080.223.....	455.77	.. .. ..	u w sp; II?
3078.833.....	70.42	.. .. ..	P_2; II?
3070.824.....	555.10	.. .. ..	u w sp; II?
3067.733.....	87.90	.. .. ..	u w sp; II?
3063.125.....	636.94	.. .. ..	u w sp; II?
3063.026.....	38.00		
3049.100.....	787.06	.. .. ..	u w sp; II?
3046.954.....	810.11	.. .. ..	u w sp; II?
3034.058.....	949.56	.. .. ..	P_2; II?
3008.491.....	33229.60	.. .. ..	P_2; II?
2993.800.....	392.66	.. .. ..	u w sp; II?
2988.232.....	454.87	.. .. ..	u w sp; II?
2983.825.....	504.28	.. .. ..	u w sp; II?
2981.42.....	31.3		u w sp; II?
2978.64.....	62.6	.. .. ..	P_2; u w sp; II?
2968.692.....	675.07	.. .. ..	u w sp; II?
2964.924.....	717.86	.. .. ..	u w sp; II?

TABLE 2—*Continued*

λ	ν	− o +	Remarks
2961.49.....	33757.0	. . . . .	u w sp; II?
2957.922.....	97.67	. . . . .	u w sp; II?
2942.864.....	970.60	. . . . .	P_3; II?
2932.67.....	34088.7	. . . . .	u w sp; II?
2932.51.....	90.4	. . . . .	II?
2928.253.....	140.09	. . . . .	u w sp; II?
2925.06.....	177.3	. . . . .	P_3; u w sp; II?
2910.599.....	347.15	. . . . .	r; II?
2899.727.....	475.93	. . . . .	u w sp; II?
2898.97.....	84.8	. . . . .	P_2; u w sp; II?
2897.074.....	507.50	. . . . .	u w sp; II?
2895.133.....	30.64	. . . . .	P_3; II?
2892.174.....	65.96	. . . . .	u w sp; II?
2891.79.....	70.5	. . . . .	u w sp; II?
2887.821.....	618.06	. . . . .	u w sp; II?
2885.053.....	51.27	. . . . .	u w sp; II?
2884.295.....	60.38	. . . . .	u w sp; II?
2870.39.....	828.1	. . . . .	R; P_1; u w sp; II?
2861.37.....	938.0	. . . . .	r; P_2; u w sp; II?
2851.25.....	35062.1	. . . . .	u w sp; II?
2842.81.....	166.0	. . . . .	P_3; II?
2837.299.....	234.45	. . . . .	R; u w sp; II?
2834.481.....	69.48	. . . . .	r; II?
2832.317.....	96.42	. . . . .	R; P_2; u w sp; II?
2824.67.....	392.0	. . . . .	u w sp; II?
2771.54	36070.4	. . .	P_2; II?
2768.87.....	105.2	. . . . .	P_2; II?
2764.66.....	60.0	. . . . .	P_2; II?
2752.18.....	324.2	. . . . .	P_2; II?
2747.17.....	90.3	. . . . .	P_2; II?
2729.34.....	627.9	. . . . .	P_2; II?
2722.38	721.7		P_2; II?
2716.32.....	803.5	. . . . .	P_2; II?
2708.19	914.1		P_2; II?
2703.96	971.8		P_2; II?
2695.24.....	37091.3	. . . . .	P_3; II?
2693.98.....	108.6	. . . . .	u w sp; II?
2692.43.....	30.0	. . . . .	P_3; II?
2687.15.....	203.0	. . . . .	u w sp; II?
2686.19	216.4		P_3; II?
2684.31.....	42.3	. . . . .	r; P_3; II?
2625.75.....	38072.9	. . . . .	P_2; II?
2618.83	173.5		P_2; II?
2600.90	436.8		P_2; II?
2597.06.....	93.6	. . . . .	P_2; II?

TABLE 2—*Continued*

λ	ν	− o +	Remarks
2583.37.....	38697.4	.. .. ..	r; P_2; II?
2571.61.....	874.4	.. .. ..	P_2; II?
2564.38.....	984.0	.. .. ..	P_3; II?
2555 23	39123 5	.	P_1; II?
2554.73.....	31.4	.. .. ..	r; P_1; II?
2549.55.....	210.8	.. .. ..	P_1; II?
2549.12.....	17.5	.. .. ..	P_1; II?
2475.32.....	40386.5	.. .. ..	r; II?
2463.68.....	577.4	.. .. ..	r; II?
2441.29.....	949.5	.. .. ..	r; II?

partly by the writer. The *Th* II lines appeared only at the higher temperatures. The lines are designated "fur" in the tables.

Further work done by the writer includes the observation of lines emitted in the underwater spark. No lines of thorium were observed in absorption in the spark; only emission lines appeared.[13] These emission lines are marked "u w sp" in the tables. It will be observed that most of these lines are also emitted in the furnace and consequently this group is probably a somewhat enlarged list of *Th* II low-temperature lines.

The *J*-values quoted in the tables under "Remarks" were obtained by Ference, Bowersox, and Fred from Zeeman patterns of the thorium arc in a field of 30,000 gauss, photographed on the twenty-one-foot grating up to the fourth order. Most of the patterns could not be completely resolved, and a thorough Zeeman analysis with the thirty-foot grating is being undertaken at the present time.

The results of Pollok and Leonard[14] on the persistent lines observed with solutions of thorium are quoted as follows:

P_1, Line appears at 0.01 per cent *Th*
P_2, Line appears at 0.1 per cent *Th*
P_3, Line appears at 1.0 per cent *Th*
P_4, Line appears in strong solution

Lines found by Allin[15] to be reversed in the underwater spark are designated "r." The interpretation of these lines is doubtful. Lines

[13] Cf. W. F. Meggers and O. Laporte, *Phys. Rev.*, **28**, 642, 1926.

[14] *Op. cit.* [15] *Op. cit.*

marked "R" were reversed on plates taken by Ference, Bowersox, and Fred with an arc current of thirty amperes in nitrogen at a pressure of seven atmospheres.

Because of space limitations, only the most important lines are given below. Practically all *Th* I lines with an intensity of 2 or more are included. The *Th* II table consists of only the low-temperature lines and the *raies ultimes*. The importance and classification of the *raies ultimes* for which stigmatic intensities are not given (because the enhancements are not well pronounced) are not so well founded but are included by analogy with similar lines in the zirconium spectrum,[16] which are mostly *Zr* II.[17] Likewise, the underwater spark lines in the ultraviolet are merely assumed to be low-temperature *Th* II by comparison with the rest of the spectrum.

It is believed that the value of the table lies not in the wave lengths but in the selection of the most important lines. Nevertheless, the accuracy should be great enough to permit a term analysis for *Th* I, and this work is now in progress. The analysis of *Th* II will probably require the more complete set of Zeeman patterns and Harrison's more complete wave-length tables. Some constant differences have been found for both spectra.

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[16] Twyman, p. 96.

[17] C. C. Kiess and H. K. Kiess, *Bur. Stand. Jour. Res.*, **5**, 1205, 1930.